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GROWTH AND SOIL MOISTURE IN THINNED LODGEPOLE PINE

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ABSTRACT

A lodgepole pine levels-of-growing-stock study showed that trees growing at lower stand densities had longer crowns and grew more rapidly in diameter but did not grow significantly faster in height. Gross cubic-volume increment decreased with decreasing stand density. The decrease was small per unit of density at the higher densities but much greater at the lower densities. However, at the lower densities more wood is being added to the larger trees that can reach usable size. Soil moisture withdrawal was reduced at the lower stand densities. Understory vegetation did not develop strongly even at the low stand densities. This fact may have been partly responsible for the sharply increased diameter growth rate and reduced evapotranspiration drain on stored soil water at low densities.

Keywords: *Soil moisture, stand density, lodgepole pine, forest measurement.*

ACKNOWLEDGMENT

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INTRODUCTION

Reward from thinning lodgepole pine (*Pinus contorta* Dougl.) may be greater than that from thinning most other species. Only a small portion of the wood produced in natural stands is on merchantable trees, and in many especially dense stands only an occasional merchantable tree is grown. The unusable trees die or are knocked down at the time of logging to become a residue problem (fig. 1).

Figure 1.–A major portion of the total wood produced by dense natural lodgepole pine stands ends up as unused residues that are costly to dispose of.

Results of the levels-of-growing-stock study reported in this paper indicate that foresters can capture most of the total wood production on usable-sized trees by controlling stand density. Furthermore, the low density that looked best for timber production up to the present stand age also withdrew less water from the soil.

STUDY AREA

The Twin Lakes levels-of-growing-stock study is located on the Deschutes National Forest near Twin Lakes and Wickiup Reservoir. It is about 10 miles west of the Pringle Falls Experimental Forest and about 45 miles southwest of Bend at an elevation of approximately 4,300 feet.

Topography of the study area is very gently sloping toward a bowl-shaped depression with one end open. There is good water drainage.

The present young stand that originated following a fire in 1934 is primarily lodgepole pine in the lower areas. Ponderosa pine (*Pinus ponderosa* Laws.) tends to increase with only a very slight rise above the depression floor, and a rise of only a few feet completes the transition from lodgepole to ponderosa pine in most places. However, stumps of mature ponderosa pine are numerous throughout the area presently occupied by lodgepole pine, indicating that the site is capable of supporting either.

Cold air drainage into the lower portions of the area probably accounts for presence of lodgepole pine there rather than ponderosa pine. Berntsen (1967) demonstrated that, of the two pines, lodgepole is considerably more tolerant of freezing temperatures during the first spring after germination. He concluded that this greater frost tolerance of lodgepole pine accounts for its presence in many low-lying cold flats in central Oregon. Filtering in of ponderosa pine seedlings under an existing lodgepole pine canopy in a manner described by Cochran et al. (1967) could easily account for the old-growth ponderosa pines that existed in the lodgepole pine portions of the present study area. An unusually frost-free spring could also have permitted ponderosa pine establishment.

Understory vegetation makeup varies with position on the slope even though elevation changes amount to only a few feet. In the lower areas occupied predominantly by lodgepole pine, predominant plants are bitterbrush (*Purshia tridentata*), squaw currant (*Ribes cereum*), strawberry (*Frageria cuneifolia*), needlegrass (*Stipa occidentalis*), and Ross sedge (*Carex rossii*). Occasionally dogbane (*Apocynum androsaemifolium*) and princespine (*Chimaphila umbellata*) were also found. Snowbrush (*Ceanothus velutinus*) is sparsely represented. However, where even a slight slope was encountered, snowbrush tended to become the dominant understory shrub. Thus vegetation on the lower portion closely resembled the lodgepole pine/bitterbrush-currant community of Youngberg and Dahms (1970) and that on the more sloping portions, the *Pinus ponderosa/Ceanothus velutinus-Purshia tridentata* community of Dyrness and Youngberg (1966).

Soil belongs to the Lapine series.[1] It was developed from dacite pumice deposited during the eruption of Mount Mazama approximately 6,500 years ago. Total pumice depth ranged from 25 to 51 inches and averaged 37 inches at the 37 locations sampled. Plot-to-plot variation

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[1] *Personal communication with Patrick H. Cochran, soil scientist, Pacific Northwest Forest and Range Experiment Station, Bend, Oregon.*

was surprisingly small and could easily be accounted for on the basis of variation among sampling points within plots.[2]

The pumice overlays an older, predominantly sandy loam soil. The older soil profile averages 15 inches in depth to a compacted layer similar in texture to the soil above it. This layer defines the lower limit of rooting depth (fig. 2). Total depth of soil, both pumice and buried sandy loam, ranged from 42 to 62 inches and averaged 52 inches at the 12 locations sampled.

Site index for the study area as a whole averages 72 feet at age 50 years for the tallest lodgepole pine tree per one-fifth-acre plot (read from Dahms (1964) site index curves[3]). Actual tallest tree height at age 35 years averaged 52.5 feet, ranging from 49.5 to 56.2 feet.[4] These heights are considerably above averages for central Oregon lodgepole pine at 35 years.

Figure 2.—Roots of this windthrown ponderosa pine tree abruptly stopped their downward penetration when they encountered the compacted soil layer. This tree had been growing immediately adjacent to the lodgepole pine thinning area, on similar soil.

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[2] *Most of the sampling points consisted of auger holes drilled to accommodate access tubes for measuring soil moisture with the neutron probe. Pumice depth measurements were taken in the holes used for each of the first three tubes installed on each of the original 10 plots. Other depth-of-pumice measurements came from a large soil pit and from several smaller ones dug in 1970.*

[3] *Site index 72 is substantially higher than that reported by Dahms (1967) because an average of three tallest trees per plot was used to estimate 1959 site index. This was done to strengthen comparisons between plots in a very young stand. Had the single tallest tree per plot approach been followed in 1959, the answer would have been site index 70. Use of the single tallest tree per one-fifth acre is the only valid way to estimate site index for use with the gross yield table.*

[4] *Age 35 years was used because the tallest trees probably originated the first year after the 1934 fire even though stand age averages only 32 years. Site index is extremely sensitive to small errors in age in young stands.*

THE EXPERIMENT

The experiment is a levels-of-growing-stock study designed for thinning at frequent intervals. Three thinnings have been made to date, the initial one in 1959, followed by rethinnings in 1964 and 1969. Rethinnings were at the same 5-year interval used for measuring growth and were done in the fall after all trees had been remeasured.

Growing-stock levels initially chosen for testing were 7,500; 12,500; 17,500; 22,500; and 27,500 square feet of bole area per acre.[5] Density on plots selected for the two highest levels was not high enough to meet specifications in 1959. After the 1964 remeasurement, 4,000; 8,000; 12,000; 16,000; and 20,000 square feet of bole area were selected as the new density definitions. The change was made because 20,000 square feet seemed enough to fully occupy the site at one end and because density had not been reduced enough at the low end to clearly reduce cubic-volume increment.

The 1969 thinning was made to the same bole area specifications as the 1964 thinning. Basal areas corresponding to the densities of 4,000, 8000, 12,000, 16,000, and 20,000 square feet of bole area per acre in 1964 were 26.8, 45.3, 63.8, 78.8, and 95.0 square feet per acre, respectively (table 1). Well-stocked portions of the unthinned stand in 1964 contained 125 to 130 square feet of basal area per acre. Figures 3, 4, and 5 provide further help in visualizing the treatments applied.

Excess trees cut to achieve the desired densities were mainly the diseased and small individuals. However, at the two lower densities, some excellent trees were cut to reach the desired level. At the two higher densities, not all diseased or low vigor trees could be eliminated. Spacing was also a factor in choosing trees to be cut.

Limbs were lopped from the fallen trees, and many stems were cut into several lengths. Consequently, slash exerted only a minor understory suppressing effect (figs. 3, 4, and 5).

The experiment is a completely randomized design with two plots randomly assigned to each of the five levels of growing stock. Originally plots were 0.1 acre in size, the largest reasonably homogeneous plot areas that could be found if the highest density treatment were to be applied. At the time of the 1964 thinning when density definitions for all treatments were lowered, it became apparent that not enough trees would be left on 0.1-acre plots at the lower densities. Consequently, size of plots at the lowest density was increased to 0.4 acre and at the next higher density to 0.2 acre. Most of the area added

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[5] *Bole area is a close estimate of the cambium area of the tree stem. Lexen (1943) more fully describes bole area as a measure of stand density.*

Table 1.--*Stand statistics per acre after the 1959 thinning and before and after the 1964 and 1969 thinnings.*

Growing-stock level	Number of stems	Spacing[3]	D.b.h.[3]	Height[3]	Basal area	Bole area	Crown competition factor	Total volume[4]
		Feet	*Inches*	*Fee*	--*Square*	*feet*---		*Cubic feet*
After the 1959 thinning:								
1 (lowest)	405	10.4	4.2	26.0	41.7	7,330	64	542
2	610	8.4	4.4	28.2	70.0	12,454	102	978
3	925	6.9	4.0	27.2	85.3	16,538	136	1,168
4	1,345	5.7	3.4	24.6	92.4	19,305	164	1,209
5 (highest)	1,705	5.1	3.0	22.8	93.6	20,248	182	1,173
Before 1964 thinning:								
1	405	10.4	5.2	32.4	62.0	10,496	84	1,016
2	610	8.4	5.0	34.1	88.6	16,343	121	1,461
3	920	6.9	4.5	33.2	107.4	21,822	158	1,806
4	1,315	5.8	3.8	30.3	113.6	24,700	184	1,765
5	1,645	5.1	3.4	27.9	115.4	25,078	201	1,725
After 1964 thinning and plot enlargement--individual plot equations:[1]								
1	114	19.5	6.5	37.3	26.8	4,264	32	460
2	260	12.9	5.6	35.8	45.3	8,050	59	744
3	400	10.4	5.3	36.5	63.8	12,352	86	1,092
4	675	8.0	4.5	33.5	78.8	16,131	116	1,253
5	1,065	6.4	4.0	30.4	95.0	20,255	151	1,403
Spacing[2]	85	22.6	7.9	41.7	29.6	3,982	32	566
Before 1969 thinning--after additional climbed trees added:								
1	114	19.5	7.7	43.8	37.8	5,976	42	729
2	258	13.0	6.4	42.4	58.6	10,963	71	1,170
3	400	10.4	5.9	42.2	78.3	16,214	99	1,588
4	670	8.1	5.0	38.8	93.4	20,970	130	1,790
5	1,050	6.4	4.3	35.4	108.5	25,966	166	1,974
Spacing[2]	85	22.6	9.1	46.4	38.8	5,491	39	766
After 1969 thinning and plot additions:								
1	71	24.8	7.9	44.4	25.1	3,917	27	496
2	170	16.0	6.8	42.9	43.4	8,059	51	867
3	265	12.8	6.4	43.8	60.1	11,991	73	1,252
4	478	9.5	5.2	39.7	72.3	16,015	98	1,417
5	750	7.6	4.4	35.8	84.7	19,936	126	1,578
Spacing[2]	85	22.6	9.1	46.4	38.8	5,491	39	766

[1] Volume and bole area figures differ from those previously published because individual formulas were substituted. Other figures differ because of plot enlargements. However, published number of trees for 1964 after thinning was found to be slightly in error on treatments 3 and 5.

[2] Two plots added in 1963 in relatively open portions of the stand.

[3] Arithmetic average.

[4] Total peeled volume including tips and stumps.

Figure 3.–A plot of the highest density immediately after the 1959 thinning, which left 1,705 trees per acre. Only a few of the very poorest trees were cut.

Figure 4.–A plot of the lowest density immediately after the 1959 thinning. This treatment left an average of 405 trees per acre.

Figure 5.–A low density plot after the 1969 thinning. Note how slash from earlier thinnings has been flattened to the ground by snow. The only visible understory vegetation here is a few scattered bitterbrush plants.

came from the 1/2-chain buffer strip surrounding each plot. Size of the remaining six plots was increased to 0.2 acre at the time of the 1969 thinning. Small holes that had seemed too large in the 22-year-old stand in 1959 were mostly occupied by the larger 32-year-old trees in 1969 and therefore acceptable for inclusion within a plot.

Random assignment of treatments to plots after all had been chosen meant that all plots had to come from the denser portions of the original stand to be satisfactory for the highest density treatment. Consequently, there were no low density plots in portions of the stand that had started out at a low density. To remedy this situation, two additional 0.2-acre low density plots were installed in 1963. These plots were put in portions of the stand that had grown up under open conditions with good individual tree development. These plots were thinned again in 1964 to meet the new treatment definitions but no further thinnings are planned. Consequently, they are designated spacing plots. Because these plots were not a part of the original random selection, they cannot be included in most tests of significance between treatments. However, it is legitimate to make comparisons to the extent that we believe differences at the time of plot installation really stem from accidents of seedling establishment rather than real growing site differences.

MEASUREMENTS

Measurements of trees and soil moisture were made during the 10-year period from the fall of 1959 through the fall of 1969. Crown density of understory vegetation was measured during the 1970 growing season.

Tree measurements of the following kinds were made:

1. Diameter, height, and height-to-live-crown were measured on each tree in 1959, 1964, and 1969. Diameters were measured with a tape to the nearest 0.1 inch. Heights and height-to-live-crowns were measured with a sectioned pole and recorded to the nearest 0.1 foot.

2. Detailed measurements were made on a sample of trees to provide the basis for calculation of volume and bole area of each of these individuals. For this purpose caliper measurements outside bark were made at 1.0-, 4.5-, 10.0-, 20.0-, and such additional even 10-foot distances up the tree as could be reached by climbing. Initially bark thickness was measured at each calipered point. Later it was measured only at 1.0 foot above the ground and at breast height (b.h.). At higher points it was calculated on the assumption that bark constituted the same percentage of diameter outside bark as it did at breast height.

Five trees per plot, chosen on the basis of diameter, constituted the detailed measurement sample in 1959. These same trees were remeasured in 1964 before thinning. After thinning, enough additional trees were measured to bring the total number of standing climbed trees to 10 per plot. Because some of the original five climbed trees were were removed by thinning, it was necessary to add more than five trees on most plots to bring the total to 10. In 1969 the same 10 climbed trees left from 1964 were completely remeasured before thinning and enough trees added after thinning to again bring the total of standing climbed trees to 10 per plot.

3. Diameters of crowns were measured on a sample of trees. All trees at the lowest densities were measured, but at higher densities only every second, third, or fifth tree was measured, depending on the number of trees in the plot. A total of 305 crown widths were measured on all 12 plots. Diameters were measured in two directions as nearly at right angles to each other as could be determined by eye. Measurements were made with the aid of a plumb bob rigged on a pole. Tip of the pole was held at the outside of the crown and the plumb bob dropped to the ground. Actual crown diameters were measured between plumb bob points on the ground. These measurements were made only in the fall of 1969.

4. Diameters were measured to the nearest 0.01 inch with a tape to determine seasonal progress of diameter growth on the same sample trees used for crown width measurements during the 1969 growing season.

Soil moisture was measured with a neutron probe beginning in 1961. At first, frequent measurements were made during the growing season beginning immediately after snowmelt. Later, as it became apparent that the soil was fully charged each spring and that the seasonal pattern of withdrawal was similar, measurements were made only at the end of the growing season.

Four mechanically located access tubes, each 5 feet long, were used as sampling points on each plot. Readings for each tube were taken at 1-foot intervals beginning 1 foot below the soil surface. Probe readings were converted to percent moisture by volume using a calibration curve developed by Barrett (1970).

Understory vegetation crown cover was estimated in 1970 by systematically sampling each plot with approximately 100 points using methods described by Heady et al. (1959). Snowbrush, other shrubs, grasses and sedges, and herbs were the classes of vegetation recognized. No vegetation measurements were taken prior to 1970.

CALCULATIONS

Volume of individual trees was calculated using Smalian's formula for the main part of the bole. Volume of the 1-foot stump was calculated as a cylinder, and volume of the tip was obtained on the assumption that the cross-sectioned area at the half-length point would be half that at the base.

Bole area of individual trees was obtained by calculating surface area of the same sections used for volume calculations and summing them to total bole area for the tree. Each section was treated as a cylinder, with circumference obtained from the circle of average cross-sectional area. Bole area as calculated under bark was approximately equal to cambium area of the main stem.

All diameter values used for calculating volume and bole area of individual trees were based on caliper measurements. This included measurements at b. h.

Initially, volume and bole area of each completely measured tree were calculated inside bark. However, inspection of the data revealed that measurements made in 1964 showed consistently thicker bark than in either 1959 or 1969. Measurements made in 1959 and 1969 were very similar. Therefore, volumes were all calculated outside bark. Inside bark volume from the 1959 and 1969 measurements combined averaged 87.18 percent of outside bark volume. A comparison of regressions of volume D^2H for inside and outside bark showed there were no consistent trends of different percentages with tree size within the range of tree sizes encountered. Therefore, inside bark volume for all three dates was obtained by first calculating outside bark volume and then multiplying by 0.8718.

An attempt was made to similarly adjust bole area for bark measurement discrepancies. However, trends associated with tree size complicated the process to the point that unadjusted values were used.

Volume and bole area for the climbed trees were expressed as functions of diameter and height. Diameter breast high determined by diameter tape was used for this purpose to be consistent with the diameter tape measurements made on the unclimbed trees to which the equations were to be applied. One volume and one bole area equation were developed for all climbed trees on all plots in 1959 and the same trees in 1964. Volume and volume increment figures contained in Dahms (1967) were based on these equations.

Individual volume and bole area equations were developed for each plot after the additional climbed trees were added. Because the individual plot regressions for volume and bole area did not differ greatly

from the single experiment-wide ones, the individual ones were used as the basis for computing both the ending volumes and bole areas for the 1960-64 period and the beginning values for the 1965-69 period.

Volume and bole area equations for each plot in 1969 were based on all climbed trees available, including those added as replacements for the ones cut in the 1969 thinning. These equations were also used to calculate volume and bole area figures that served as ending values for the 1965-69 period and beginning values for the 1970-74 period.

The switch to individual plot volume and bole area equations, with the attendant requirement of many more climbed trees and the much greater calculation load, was made possible by computer calculations. Hand calculator computations had been envisioned when this study was in the design stage.

RESULTS

Crown

Crowns were both wider and longer at the lower stand densities in 1969 (fig. 6). These conclusions were reached from the 100 trees of largest diameter per acre. Consequently, the large number of small trees present only at the higher densities did not affect conclusions.

Crowns of the 100 largest trees were increasing in length at all densities. That is, trees were growing more rapidly in height than the lower part of the crown was receding through branch death. However, rate of increase was significantly greater at the lower densities.

Height growth of the largest trees averaged 13.4 feet during the 10-year period from 1959 through 1969 and was not significantly affected by stand density. Minor differences from one treatment to another could easily be accounted for by variations between plots treated alike.

Rate of crown recession from death to lower branches was definitely faster at the higher densities. Following is the average number of feet of crown lost over the 10-year period from 1959 through 1969 by density level:

Density level	*Crown recession* (feet)
1 (lowest)	2.35
2	4.30
3	5.35
4	5.65
5 (highest)	7.05

Differences in amount of crown lost between density levels are highly significant in a statistical sense.

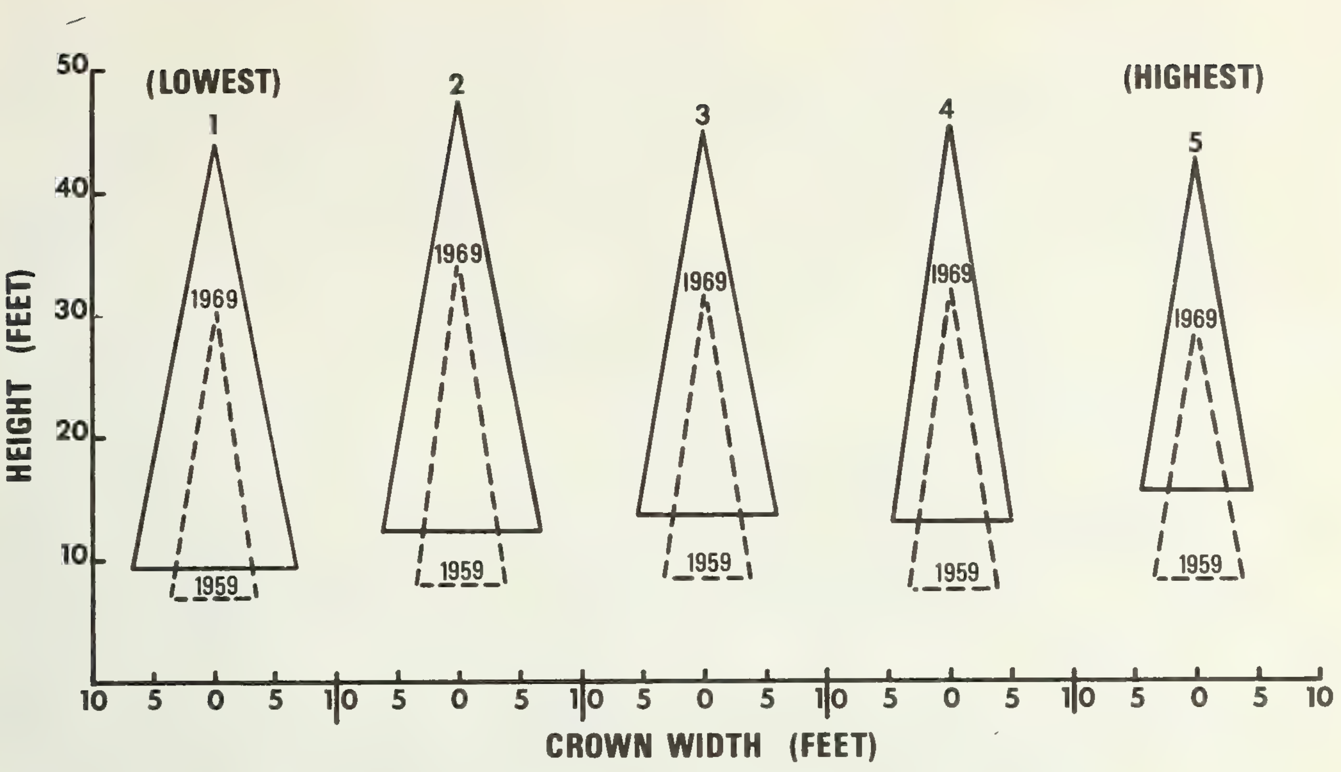

Figure 6.–Crown size of 100 largest trees per acre in 1959 and 1969 by density treatment. Crown widths for 1959 were estimated from 1969 regressions of crown width on diameter, 1959 crowns are shown as dotted lines.

Crown width increased steadily as tree diameter increased across the entire range of diameters. Regressions of crown width on stem diameter breast high within each of the density levels were all highly significant in a statistical sense. However, differences in slope of regressions between density levels were small and did not approach statistical significance.

Crowns also tended to be wider at comparable diameters for trees growing at the lower densities. Following is a comparison of crown widths among density levels before and after adjustment for diameter differences:

Growing-stock level	*Average diameter* (Inches)	*Average crown width* (Feet)	*Adjusted crown width*[6] (Feet)
Spacing[7] (lowest)	9.1	15.2	11.0
1	7.7	13.4	11.2
2	6.5	11.0	10.7
3	5.9	9.6	10.2
4	4.9	7.4	9.5
5 (highest)	4.1	6.3	9.5

[6] *Crown width adjusted to a tree diameter of 6.3 inches, the average diameter of the 305 trees on which crown width was measured.*

[7] *The spacing plots were the ones selected later in the less dense portions of the original stand. They could not be included in figure 6 because no 1959 information was available.*

A covariance analysis showed there were statistically significant differences in crown widths between density levels after adjustment to one average diameter. Evidently crown widths on trees of all sizes have been increasing relatively more rapidly than stem diameter at the low stand densities than at the high densities. Because of the longer crowns, branches on trees growing at lower densities have more years to grow. There is also a distinct possibility that branches on trees with more growing space may also grow more rapidly.

Diameter

Diameter growth was most rapid at the lowest level of growing stock and slowest at the highest levels during both periods (fig. 7). These differences in diameter growth rate between growing stock levels were statistically highly significant.

There was some tendency for diameter growth of all trees as a group to slow from the first period to the second at equivalent densities. There were also some diameter growth increases in response to additional growing space. For example, at the lowest density where the 1959 thinning left 7,300 square feet of bole area per acre but the 1964 thinning reduced it to 4,300 square feet, diameter growth increased from an annual rate of 0.20 inch to 0.24.

Diameter increase of the 100 largest trees per acre was slightly more rapid than diameter growth of all trees during both periods (figs. 7 and 8). The general trend of increasing diameter growth with decreasing stand density held for largest trees in about the same way as for all trees. Differences between levels were statistically significant during both growing periods.

Diameter growth was only weakly related to initial diameter at the higher densities, and almost no relationship existed at the lower end of the density scale. A regression of diameter growth on diameter at the beginning of the period was statistically significant on each of the four plots at the two higher density levels and on one plot at the lowest density level. However, similar regressions were not significant on seven other plots, all at the low and medium density levels. The relationship between diameter and diameter growth in this young lodgepole stand was too weak and uncertain to be of any practical value.

Diameter growth during the second period was closely related to diameter growth during the first. Regressions of second period diameter growth on first period growth for individual plots were all highly significant. They accounted for from 39 to 69 percent of the total variation. Thus past performance as indicated by growth during the first period was a good guide to future performance. However, past performance as indicated by beginning diameter in the 27-year-old

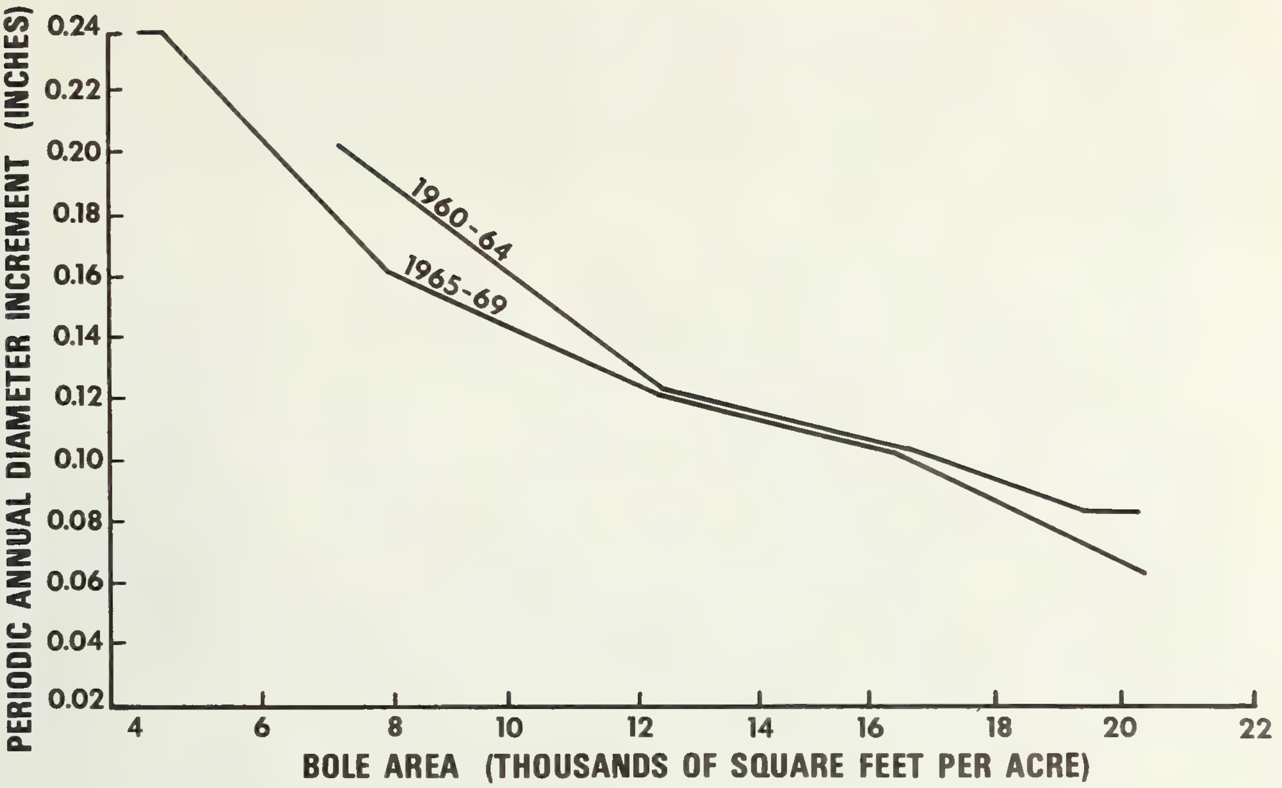

Figure 7.–Periodic annual diameter increment by period and stand density.

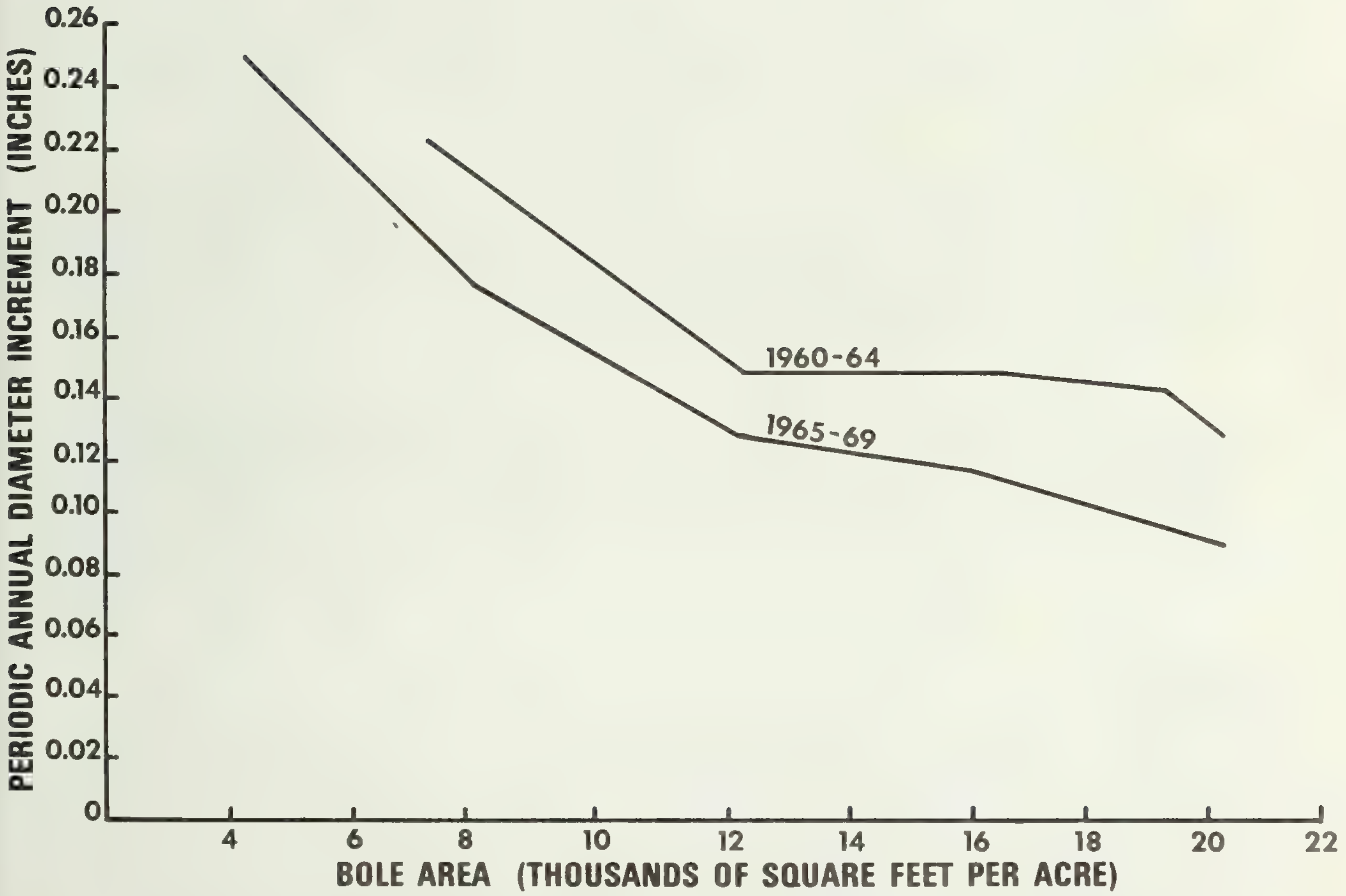

Figure 8.–Periodic annual diameter increment of 100 largest trees per acre by period and stand density.

Twin Lakes stand was not a good estimator of future performance. Although diameter is almost certainly a good integrator of average growing conditions during the life of a tree, it is not necessarily a good indicator of current growing conditions. This may be especially true when the competitive status of individual trees is modified by thinning.

Diameter growth was more strongly related to crown size than to initial diameter, but even this better relationship was not strong enough to be really useful.[8] Crown width, crown length, and width x length were the three criteria of crown size used as diameter growth predictors in regression equations. All of these equations, one for each of the six thinning treatments, proved to be significant in a statistical sense. However, percent of total variation accounted for by regression was low. It ranged from 9.5 to 32.4 percent of total variation in diameter growth. Furthermore, none of the three independent variables proved clearly superior to the others. Each proved best in two of the six equations. Thus the prospect of predicting growth rates of lodgepole pine from crown size is not encouraging.

The combination of increased growth of trees on the low density plots and increased average diameter resulting from removal of smaller trees has raised average diameter of trees at the lowest density level 3.5 inches above that at the highest level (table 1). Most of the difference, 3.2 inches, has developed during the past 10 years. Faster growth at the lowest density accounts for 1.5 inches, or about half of the total.

Diameter growth was most rapid during late spring and early summer (fig. 9). Substantial growth did not begin until after May 22 on the one plot where earlier measurements were made. As the summer advanced, growth gradually slowed; and by late August or early September, it had nearly stopped.

There was no general tendency for growth to stop sooner on high density than on low density plots. However, there were unexplained aberrations, principally on the high density plots, that cannot be dismissed as measurement inaccuracies on a few trees because the trends were common to most trees. An example is the shrinkage of trees in the 12,000- and 20,000-foot plots in late August and early September.

Height

Height growth of all trees ranged from a high of 7.7 feet on one plot to a low of 4.1 feet on another and averaged 5.8 feet during 1965-69. There was some tendency for greater growth at the lower

[8] *The analyses relating diameter growth to crown size and to diameter at the beginning of the period were both done with data from the 1965-69 period only. Crown width was measured only in 1969.*

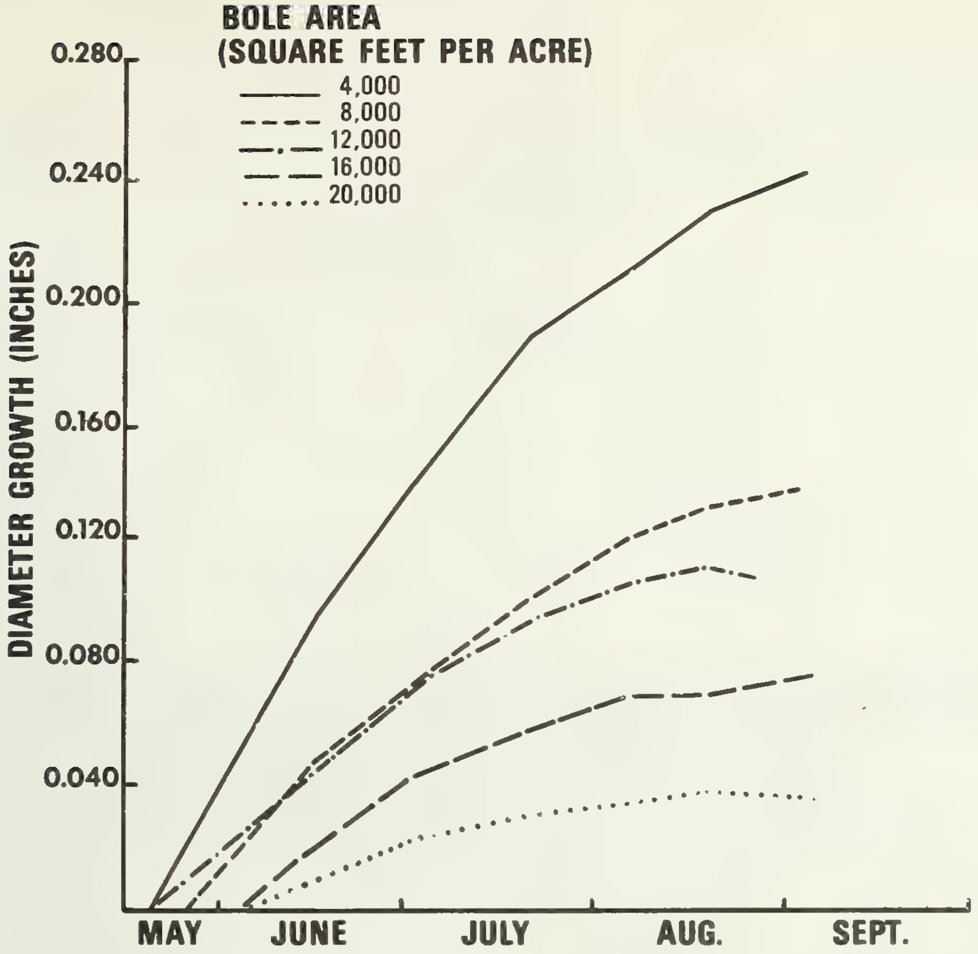

Figure 9.—Seasonal progress of diameter growth during 1969 by stand density.

densities; however, it could easily be accounted for by variation among plots treated alike. Height growth during the second 5-year period was very similar to that during the first.

Height increase of the 100 largest trees per acre was only slightly better than that for all trees. Height increase of these larger trees averaged 6.4 feet and ranged from an average of 5.4 feet on one plot to 8.0 on another.

Basal Area

Basal area increment averaged 4.2 square feet per acre annually during 1960-64 but fell to 2.7 square feet during 1965-69.[9] The drop represents mainly the normal decrease with increasing age, but lower densities at most levels during the second period were almost certainly partly responsible (fig. 10).

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[9] *These figures are for the original 10 plots only during both periods.*

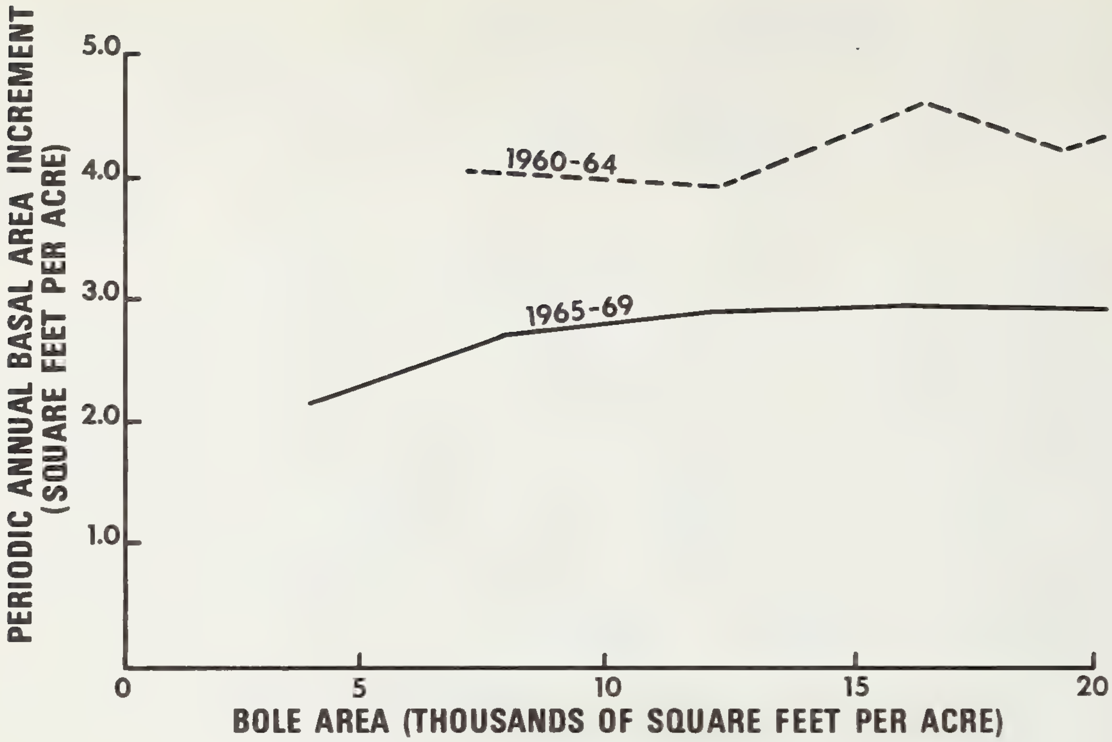

Figure 10.–Periodic annual basal area increment by period and stand density.

There was a highly significant trend of increasing basal area increment with increasing basal area during the second period (fig. 11). Variation among plots treated alike was too great to support a curved regression over a straight line. However, common sense strongly suggests a curve form that would pass through the origin, as zero basal area must produce zero basal area increment after trees have exceeded 4.5 feet in height.

There was almost no trend of increasing basal area increment with increasing bole area during the first period. Slope of a regression of basal area increment on bole area did not come close to being significant.

Volume Increment

Volume increment tended to decline from the first period to the second at comparable bole area levels (fig. 12). However, the trend was not completely consistent.

Volume increment also had a tendency to increase with increasing bole area during both periods (fig. 12). During the first period, the relationship was weak. A regression of volume increment on logarithm of bole area was barely significant at the 5-percent level. However,

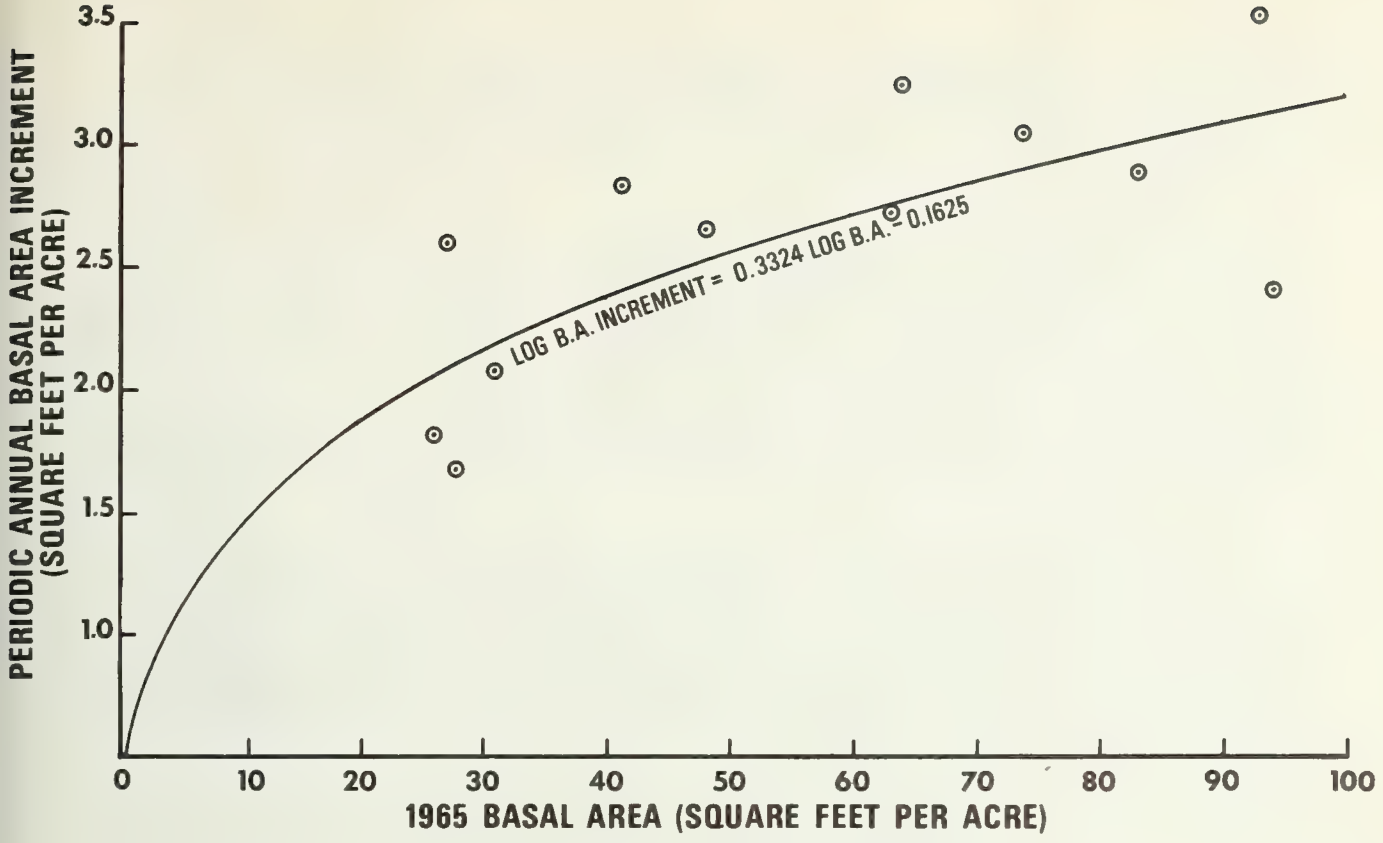

Figure 11.—Periodic annual basal area increment over initial basal area, 1965-69.

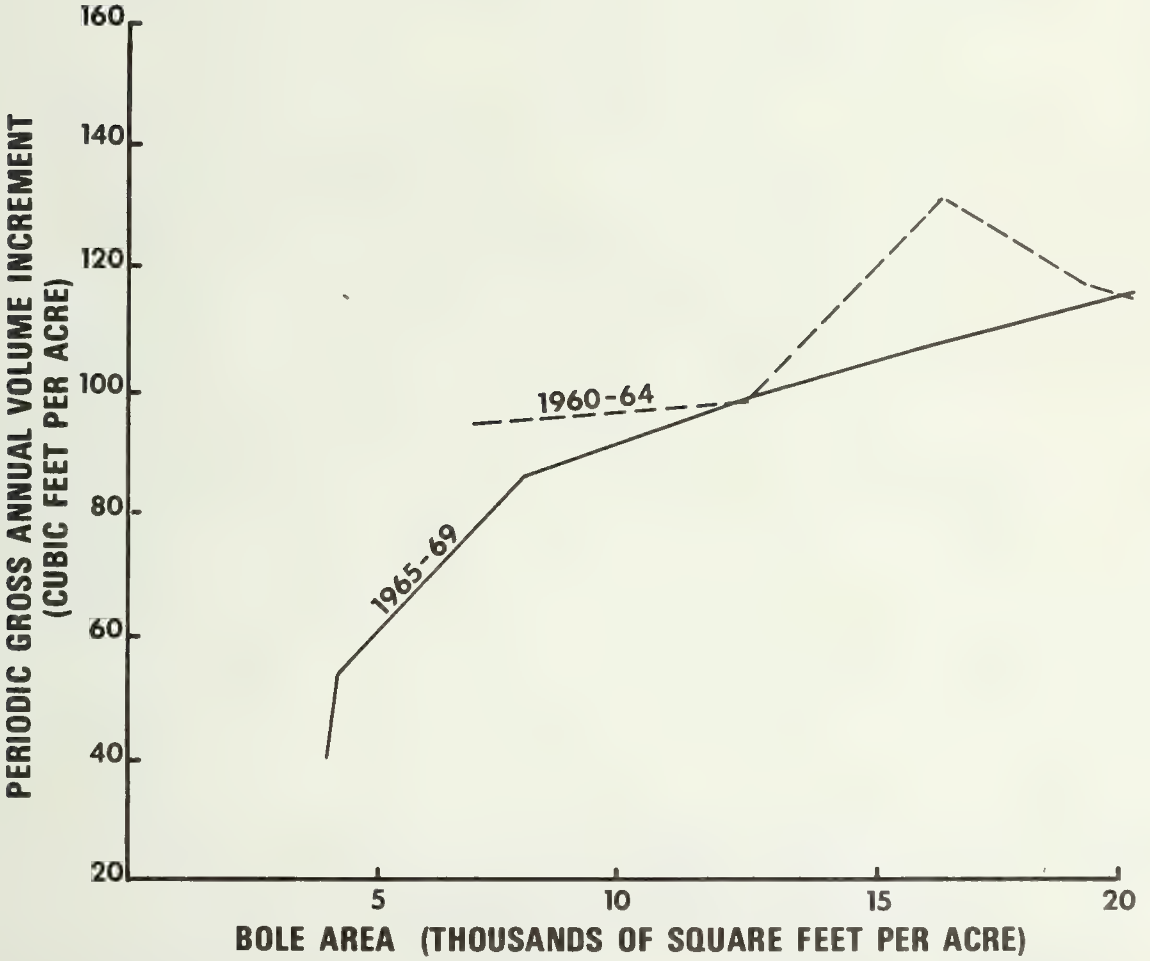

Figure 12.—Periodic annual gross cubic volume increment by period and stand density.

during the second period, a similar regression accounted for 88.0 percent of all variation and was significant far beyond the 1-percent level (fig. 13).

The stronger relationship during the second period is partly the result of a greater range of densities. The lowest level was substanially lower during the second period and therefore produced much less wood. Consequently, the range in volume increment from high to low was much greater and contrasted more strongly with the random variability among plots treated alike. There was also a tendency for plots treated alike to produce more nearly alike during the second period.

Regressions of volume increment on logarithm of basal area (fig. 14) and on logarithm of crown competition factor (CCF) (fig. 15) are very similar to the bole area regression. The bole area regression accounted for slightly more variation with the Twin Lakes data. However, the range was only from a low of 85.5 percent with the CCF regression to a high of 88.0 percent with the bole area regression.

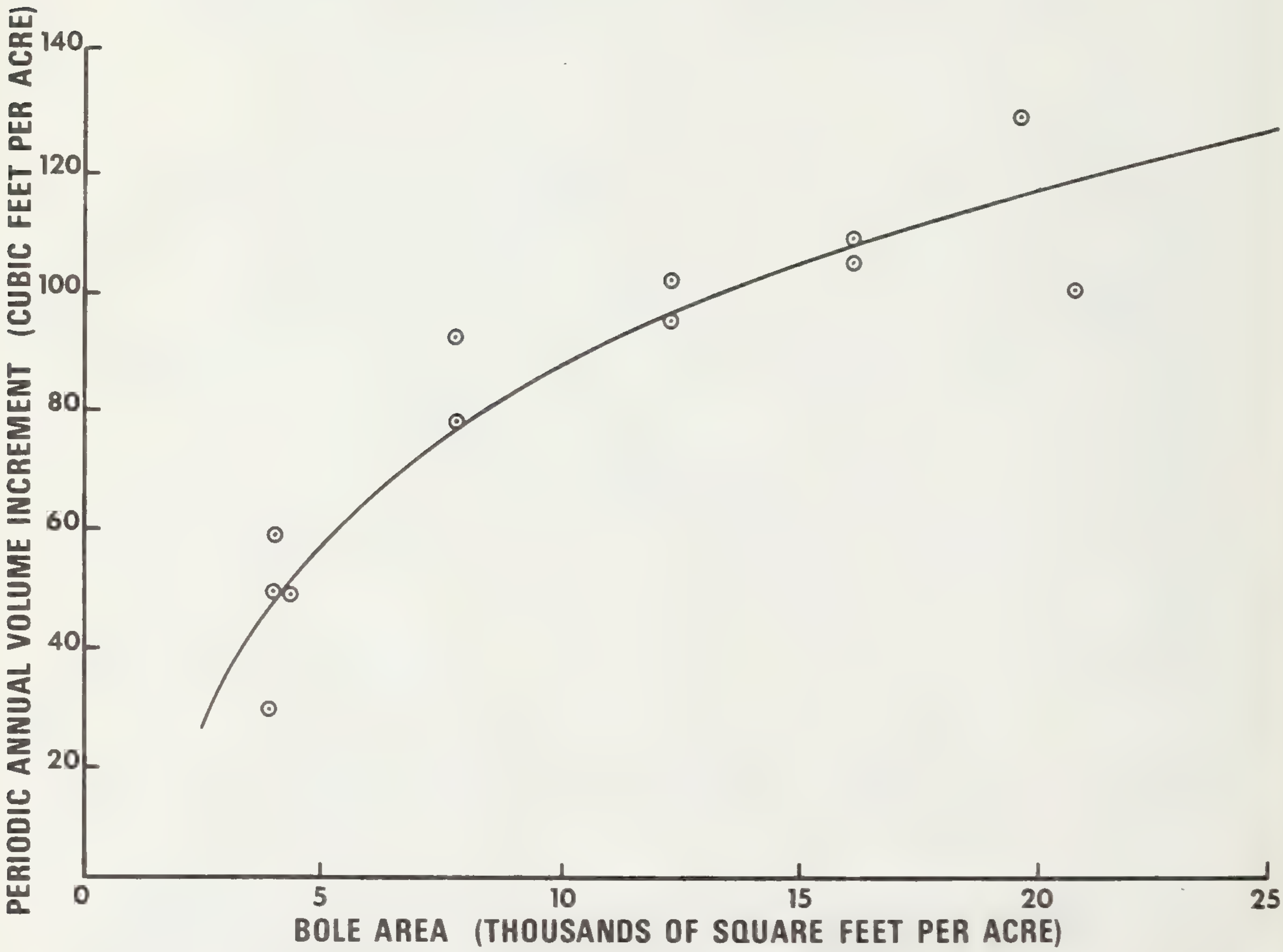

Figure 13.—Regression of periodic annual gross volume increment on log of bole area, 1965-69.

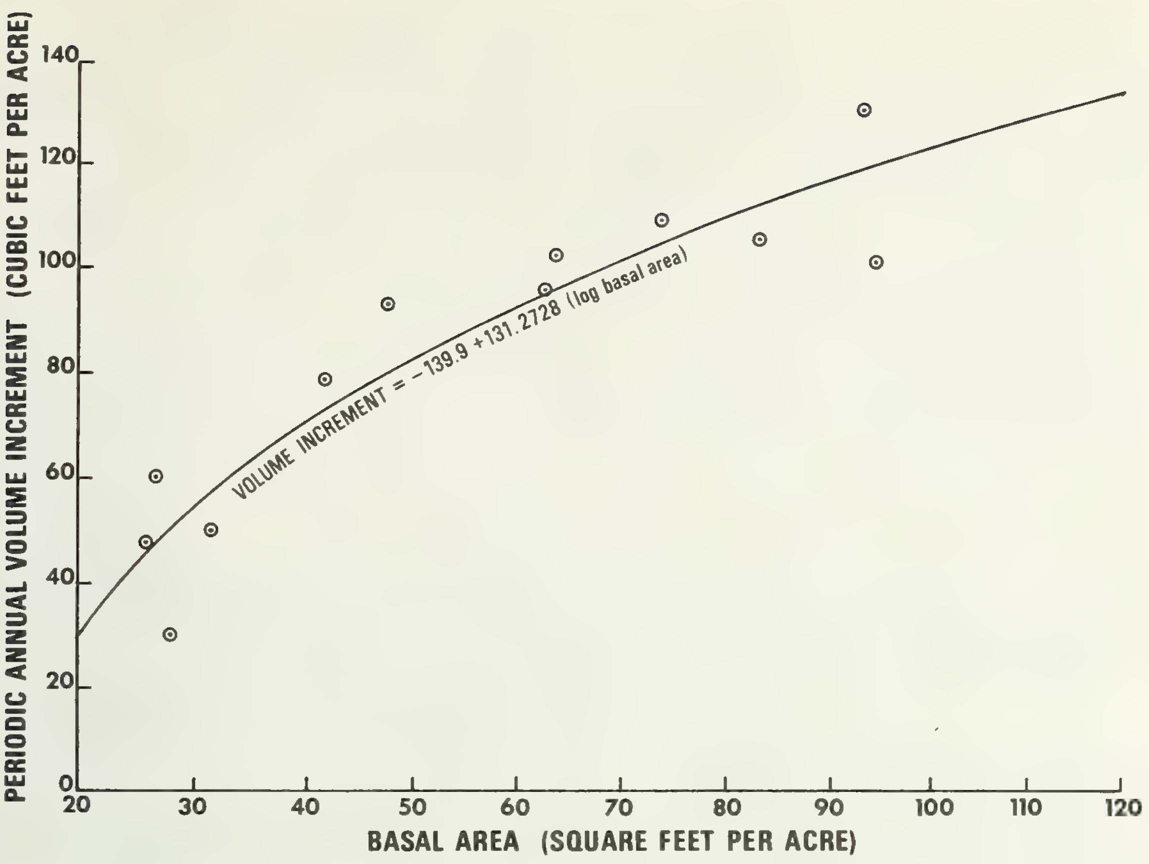

Figure 14.—Regression of periodic annual gross volume increment on log of initial basal area, 1965-69.

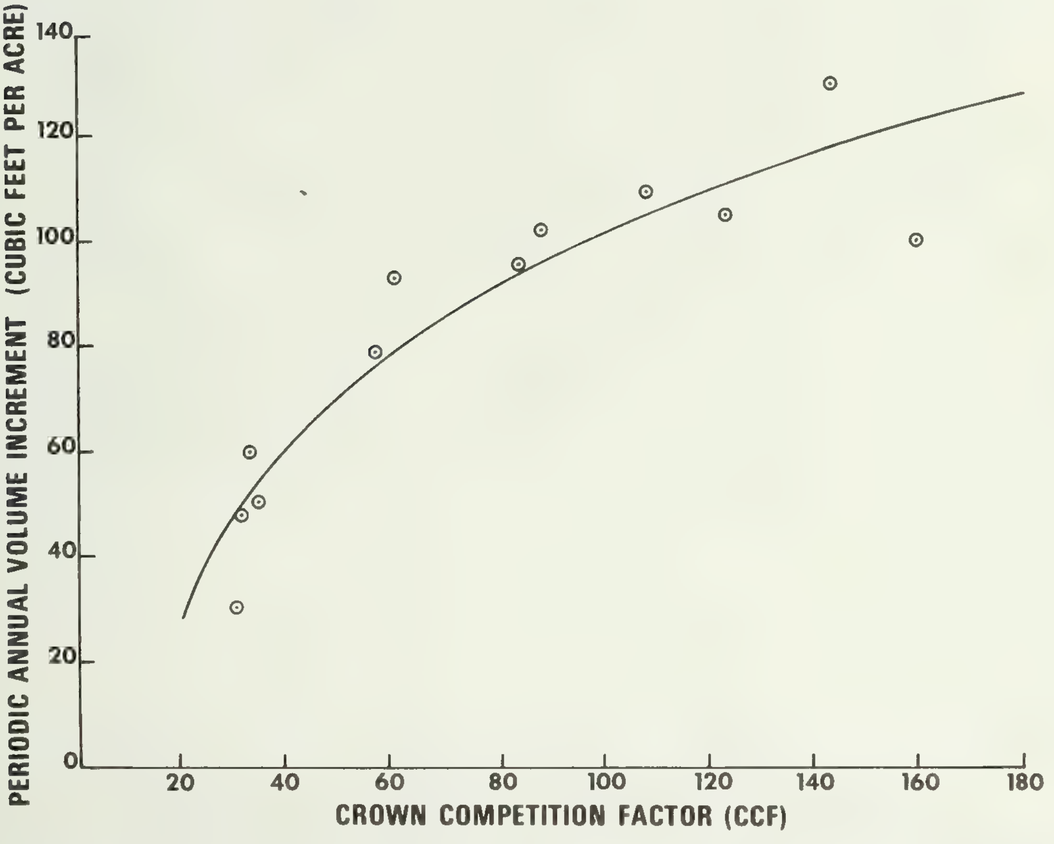

Figure 15.—Regression of periodic annual gross volume increment on log of CCF, 1965-69.

The area-occupied concept of crown competition factor can be examined in the light of actual production records. At a CCF of 33-1/3, the regression estimate of volume increment is 51.8 cubic feet per acre annually (fig. 15). Theoretically at this density trees with crowns the size of those possessed by open grown trees would form only one-third of a complete crown canopy. However, if we assume trees growing at this density are using only one-third of the site, we arrive at a full site capacity of 155.4 cubic feet per acre annually. Actual production at the higher densities (figs. 12 and 15) suggests the upper limit is somewhere in the range of 120 to 130 cubic feet per acre annually. Similarly a regression estimate of volume increment for CCF 100 is only 101.8 cubic feet per acre annually, seemingly somewhat below the full potential of the site. Thus at very low densities, lodgepole pine trees at Twin Lakes actually occupied more than the area indicated by the CCF equation; but at higher densities, they did not occupy as much area as estimated if we accept wood production as evidence of site use.

Volume increase of the 100 largest trees per acre was definitely greater during the second period than during the first. There was also a trend of more rapid increase at the lower densities than at the higher ones (fig. 16). This means that growth capacity is being transferred to the larger, more useful trees with the passage of time and that the process is taking place more rapidly at the lower densities.

Volume increment was much more sensitive to changes in stand density than was basal area increment. For example, during the first

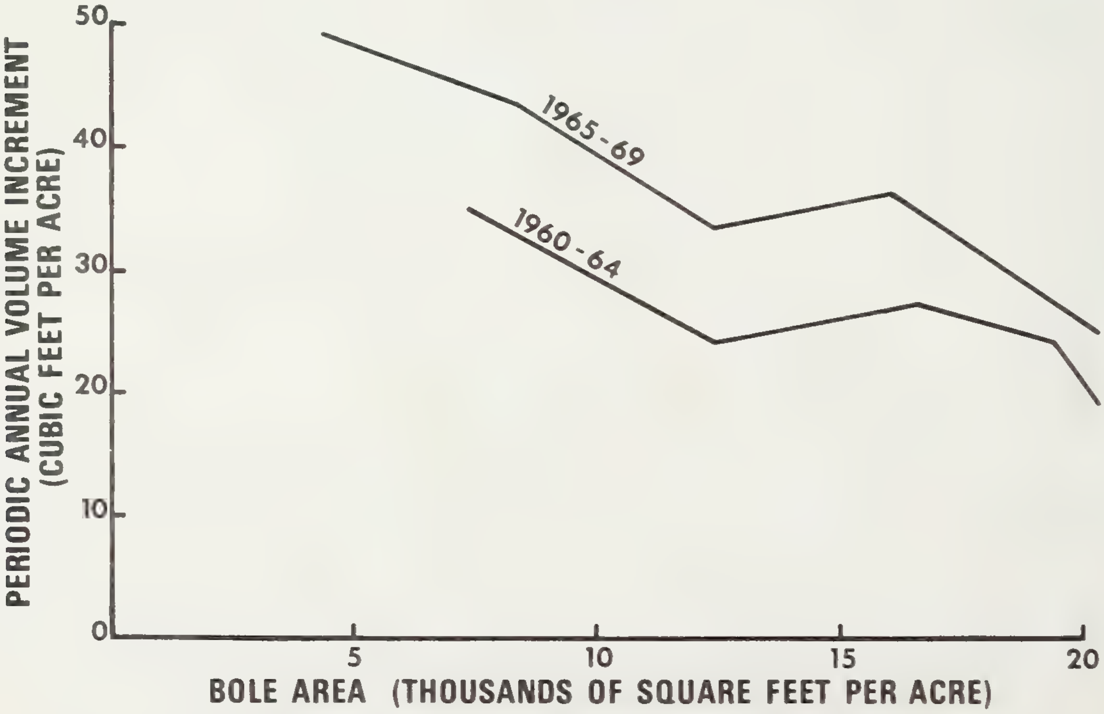

Figure 16.–Periodic annual volume increment of 100 largest trees per acre as related to stand density.

period, a regression of basal area increment on logarithm of basal area did not approach significance. However, a regression of volume increment on logarithm of bole area was significant. Similarly, during the second period, a regression of basal area increment on logarithm of basal area accounted for only 52.2 percent of all variation. But, a regression of volume increment on logarithm of bole area accounted for 88 percent of all variation. The closer relationship between stand density and volume increment suggests that more precise results can be achieved by measuring volume increment directly than by using separate estimates of basal area increment and height increment to predict volume increment.

Bole Area

Bole area was initially chosen as the measure of stand density to be used with lodgepole pine levels-of-growing-stock studies for the following two reasons.

1. Bole area closely approximates cambium area on the main stem. Thus average thickness of the annual sheath of wood added each year times bole area equals cubic volume increment. This relationship can be useful on either an individual tree basis or an area basis.

2. It is believed that a given bole area level will represent a nearly constant level of competition for most of the life of a stand once peak annual volume increment is achieved. If a constant bole area does mean a constant level of competition, the average thickness of the annual sheath of wood laid on each year would decline with increasing age in direct proportion to the decline in gross cubic volume increment per unit of area.

Trends that have taken place in the Twin Lakes study suggest that a constant bole area level means declining levels of basal area and CCF. However, a 32-year-old thinning study at Pringle Falls has shown that a nearly constant bole area means a rising level of basal area or that basal area rises more rapidly than bole area in relative terms. Also, CCF tended to change nearly in direct proportion to bole area on some plots but not all (Dahms 1971). Failure to measure bark thickness accurately at Twin Lakes in 1964 may be causing some false apparent trends there.

The idea that a constant bole area over time may represent a nearly constant level of competition receives support from the Pringle Falls lodgepole pine thinning study (Dahms 1971) and the Twin Lakes study considered together. Twelve thousand square feet of bole area per acre seems almost enough for the site at Twin Lakes.

At Pringle Falls, trees on the heavily thinned plot that had grown back to 12,587 square feet of bole area per acre by 1966 produced almost exactly as much gross increment as the unthinned check plot during the decade from 1957 through 1966. Stand age went from 78 to 87 years during this period. Thus preliminary indications are that a given level of bole area has similar stand density implications over a broad age range.

Others have thought of bole area as one of the best tools for controlling stand density for research purposes. Smith (1962, p. 102) states "The most logical parameter, bole surface area per acre, was proposed by Lexen (1943)." Once good stand density regimes are worked out in bole area terms, they can be translated into more easily used measures of stand density.

Predicted Increment

Predicted increment figures obtained from the gross yield table (Dahms 1964) agree closely with actual yields obtained during the past 10 years. Entering the gross yield table increment equation with a CCF (density) value of 166, which is the average for the two plots of highest density just before thinning in 1969, gives an estimated per-acre increment of 118.7 compared with an actual of 114.9.

If we enter the gross yield table equation with a CCF value of 189, which is the average density of 32-year-old stands used to develop the equation, the estimated increment figure is 136.1 cubic feet per acre. If we assume that a higher density for the Twin Lakes plots would not increase actual increment, predicted volume increment is 21.2 cubic feet higher than actual. However, if we assume that actual volume increment would increase with increasing density as indicated by extrapolating the volume increment on log of CCF equation (fig. 15), actual increment would rise to 130.7 cubic feet per acre or 5.4 short of predicted. Difference between actual and predicted volume increment ranged from 3.8 to 21.2 cubic feet per acre per year, depending on what assumptions were made, a reasonably good correspondence.

Close correspondence between predicted increment figures from the gross yield table and actual growth figures from the present Twin Lakes study and from the Pringle Falls thinning study (Dahms 1971) leads to the conclusion that managed stand yields can be approximated from a combination of thinning study results and the gross yield table. As an example, a thinning schedule was developed based on the idea that thinning to 12,000 square feet of bole area per acre every 10 years will produce 85 percent of the gross yield table cubic volume increment estimate.[10] Currently, confidence in such schedules is low. However,

[10] *This unpublished thinning schedule is on file at the Silviculture Laboratory, Pacific Northwest Forest and Range Experiment Station, in Bend, Oreg. It was developed at the request of the Winema National Forest and the Station's production economics project.*

as more data become available from existing studies, stand models that will permit comparisons between various management alternatives should be possible.

Understory Vegetation

Understory vegetation did not develop vigorously on the Twin Lakes plots (fig. 17). Amount of ground covered in 1970, 11 growing seasons after the first thinning, ranged from a low of 3 percent on one plot to a high of 27 on another and averaged 17.3 percent. If there were any effect of thinning-established tree density regimes on understory vegetation, it was small and completely masked by differences that existed prior to thinning.

Figure 17.–A plot of the middle density (400 trees per acre) with almost no understory vegetation. Photograph taken just before the 1969 thinning.

Snowbrush, other shrubs, grasses and sedges, and forbs ranked in that order in amount of crown cover. Snowbrush was recorded on only three of the 12 plots, but on one it covered 21 percent of the ground.

Soil Moisture

Average annual soil moisture withdrawal was greater at the higher density levels over the period 1961-70 (fig. 18). Differences between levels were significant at the 95-percent confidence level. This is the kind of result that generally is to be expected where forest vegetation density is reduced (Packer and Laycock 1969).

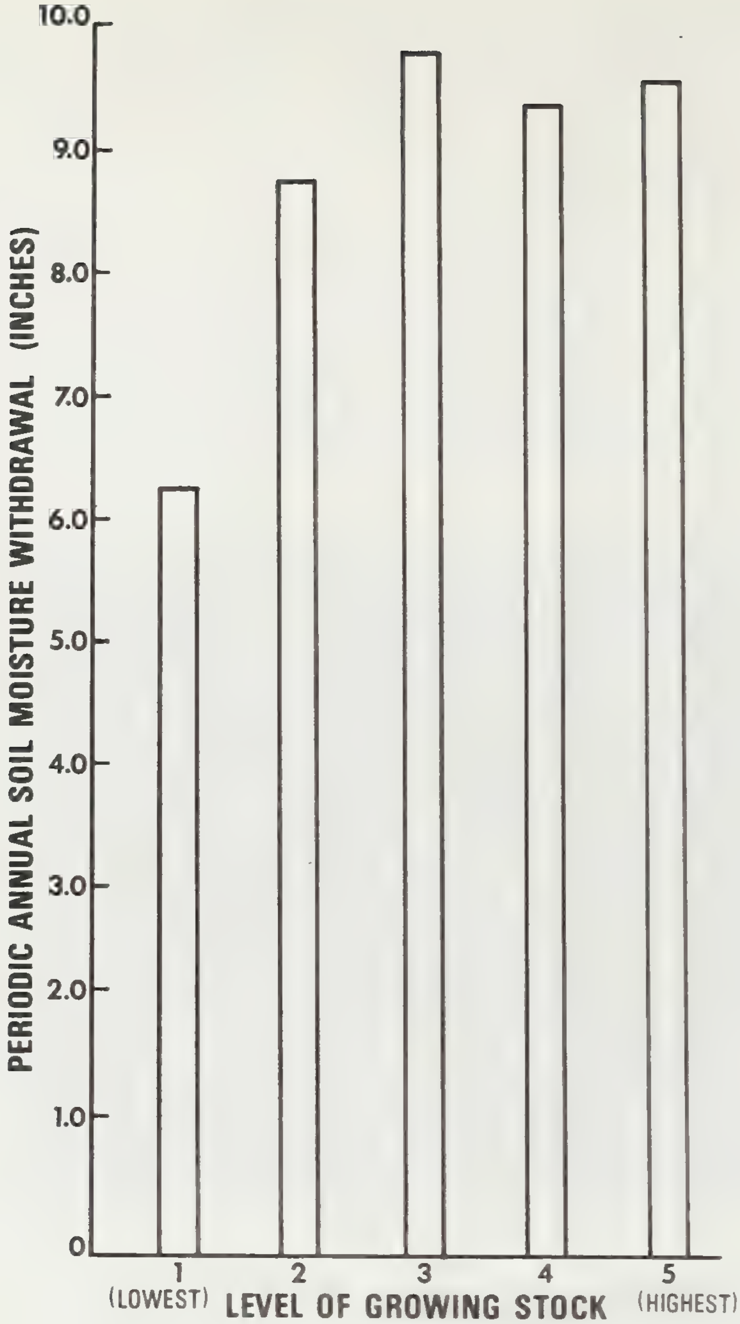

Figure 18.—Periodic annual soil moisture withdrawal by growing-stock level, 1961-70.

Growing-stock level did not affect soil moisture withdrawal consistently every year (fig. 19). In 1961, differences between levels were statistically significant. However, by 1962, crowns and roots had expanded and soil moisture withdrawal at the lower densities had increased relative to that at the higher ones. Consequently, differences were no longer significant. This situation continued until after the thinning in the fall of 1964. During 1965, differences in soil moisture withdrawal were again significant and continued through

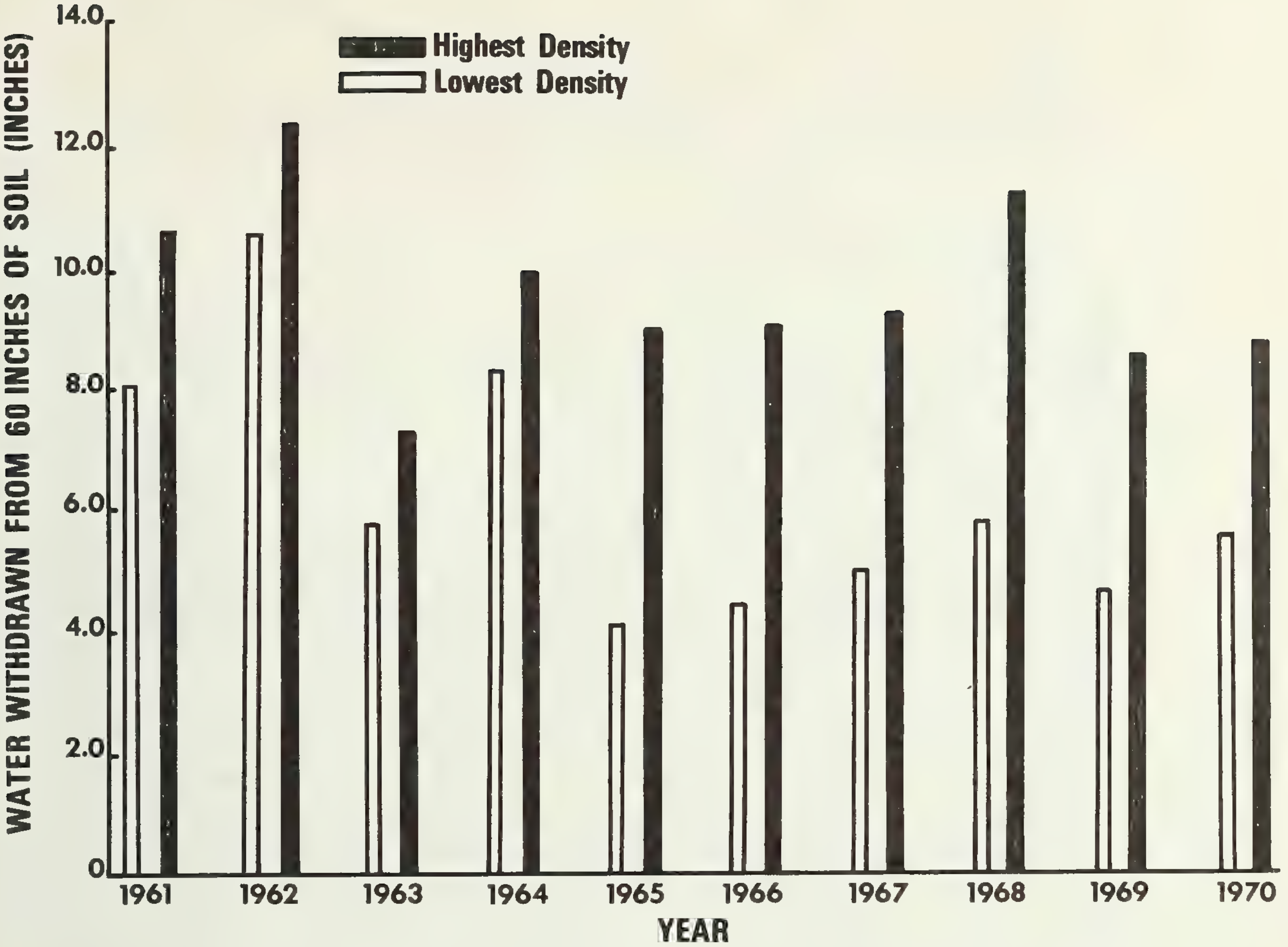

Figure 19.–Inches of water withdrawn from 60 inches of soil at the highest and lowest densities, by years.

1969. Crowns and root systems of the lesser number of trees remaining at the lower densities, after the more drastic 1964 growing-stock reductions, were not able to expand enough to make full use of the available soil moisture before the thinning at the end of the 1969 growing season. This tendency for growing-stock levels to affect soil moisture use differently from year to year was significant well beyond the 99-percent confidence level.

Soil moisture was withdrawn largely from the upper part of the soil during the early part of the season (fig. 20). However, as the summer advanced and most of the water in the upper portion of the soil had been used, soil moisture from the deeper layers was required for transpiration demands. For example, from May 4 to June 16 several times more water was withdrawn from the upper foot of soil than from the deepest measured foot. However, from July 24 to September 19 substantially more was withdrawn from the deepest foot (fig. 20).

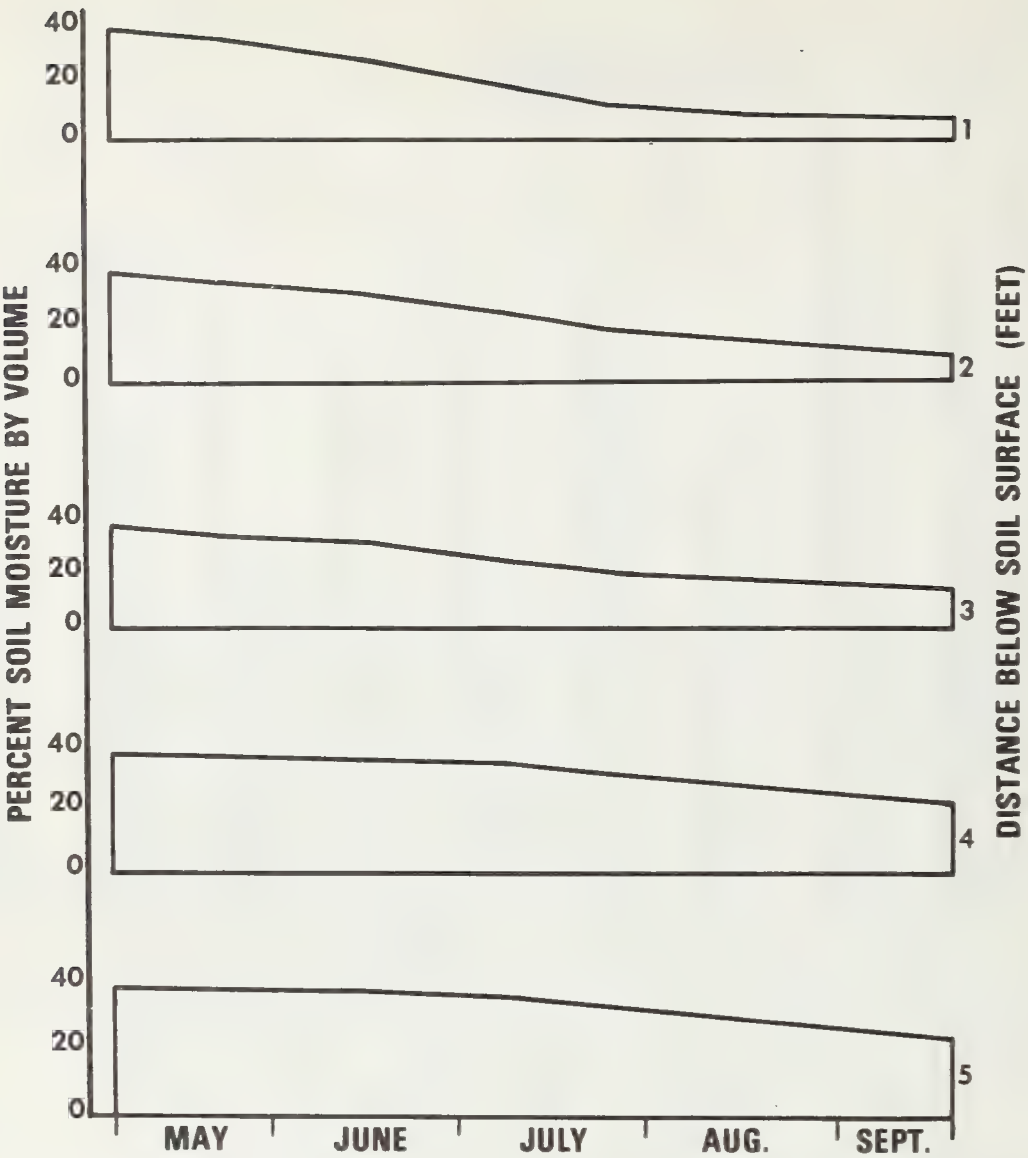

Figure 20.–Average soil moisture percent by volume during the growing season for all treatments, 1961-70.

Stored soil moisture plus precipitation appeared to be adequate to meet the evapotranspiration demand during the growing season. This conclusion is based primarily on the close agreement between the excess of estimated evapotranspiration[11/] over precipitation and actual soil moisture withdrawal (fig. 21). Ability of the trees to obtain water at an undiminished rate through July and into August is further evidence in support of the conclusion that there was enough water to meet the evapotranspiration demand.

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[11] *Potential evapotranspiration was obtained from Johnsgard (1963). His calculation was based on weather records from the Fall River fish hatchery and on the Thornthwaite-Mather procedure. The Fall River weather station is approximately 10 miles from Twin Lakes.*

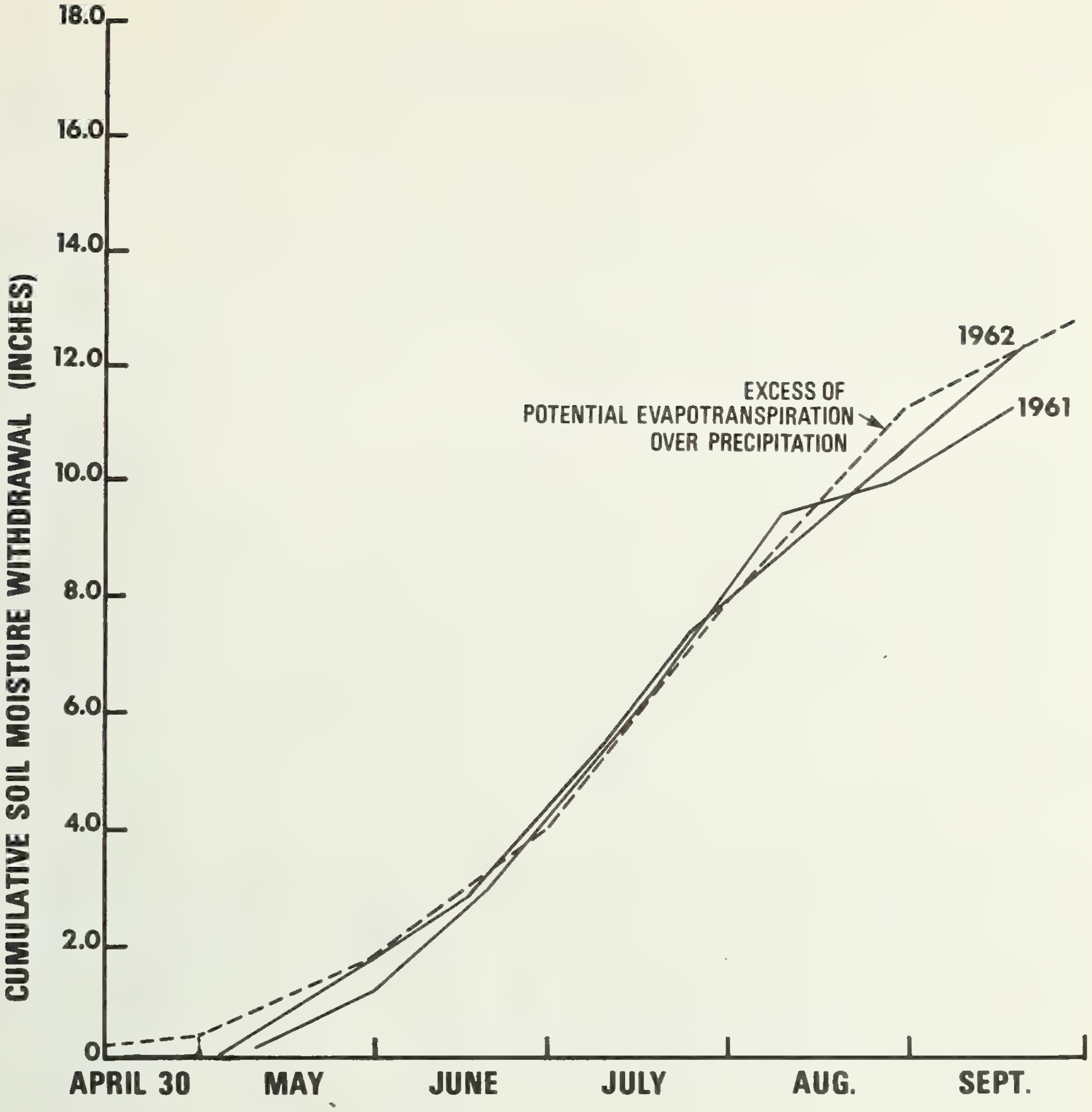

Figure 21.–Seasonal progress of soil moisture withdrawal, compared with potential evapotranspiration, from top 60 inches of soil during 1961 and 1962.

Small differences between actual soil moisture withdrawal and that predicted as the difference between potential evapotranspiration and precipitation are the result of small climatic differences between Fall River and Twin Lakes (see footnote 11), and seasonal variations. The last snow normally melts a week or 10 days later at Twin Lakes than at Fall River. Hence actual soil moisture withdrawal at Twin Lakes was slower in starting than the estimated potential at Fall River. A rainy, cloudy period between August 9 and 28 in 1961 accounts for the sharp drop in soil moisture withdrawal during that period.

DISCUSSION

Stand density control has been effective in transferring wood production from the many small useless stems to a lesser number of more valuable ones. During the 10-year period of the Twin Lakes study, approximately twice as much wood has been added to the 100 largest trees at the lowest density level as at the highest. Even though this comparison would seem to imply that no more than 100 trees can reach usable size, it is reasonably useful because by far the largest part of the usable volume is contained in the 100 largest trees.

One might also visualize the process of transferring wood production onto usable-sized trees by starting with the 85-trees-per-acre spacing treatment. Total cubic volume production is only about one-third of that at the highest density. However, the tree of average diameter (9.1 inches) has already reached usable size. Consequently, all wood produced is on trees that now are or very soon will be merchantable. Furthermore, the rapidly increasing stand density (bole-area, basal-area, etc. increases with tree size) means volume increment will be increasing rapidly relative to the high density treatment.

Although 85 trees per acre may be below the optimum stand density, all trees will be well above minimum usable size before any more thinnings are needed. The current annual production of 42 cubic feet per acre on trees that are or will be usable size is far above the merchantable wood growth obtained in natural stands. If wood growth could be continued at this rate until trees reached an average diameter of 14 to 15 inches (which is likely), annual board-foot production would amount to approximately 210 board feet per acre.

Understory vegetation did not develop as rapidly at Twin Lakes as it did on the Pringle Falls ponderosa pine spacing study. At Pringle Falls there was a definite trend of increasing understory crown density with decreasing number of trees and with the passage of time since thinning. Understory crown density reached a high of 47 percent at 125 trees per acre 9 years after the thinning (Barrett 1970). In contrast, understory vegetation at Twin Lakes showed no relationship to tree spacing and reached an average crown density of only 17 percent in 1970, 11 years after the first thinning.

Nontree understory vegetation may have had a slightly better opportunity to develop on the Pringle Falls study because the understory sapling stand was thinned very soon after the old-growth pine overstory was removed. Consequently, a large amount of new growing space, that the newly thinned suppressed sapling stand was incapable of using immediately, was made available. Because the Twin

Lakes lodgepole pine stand was in a vigorous growing condition, trees left after thinning were probably in a better position to compete with understory vegetation for the new growing space than the Pringle Falls trees.

Other factors also appear to be influencing differences in understory development between the Twin Lakes levels-of-growing-stock study area and the Pringle Falls spacing study. Differences in environment implied by understory species differences between the two areas are almost certainly involved. Observation shows that understory vegetation in the ponderosa pine stand surrounding the lodgepole pine study area is much denser. The ponderosa pine originated following the same 1934 fire that gave rise to the lodgepole pine stand and was thinned in 1957 only 2 years before the lodgepole study area was thinned. The ponderosa pine is growing in the same *Pinus ponderosa/Ceanothus velutinus-Purshia tridentata* community found on the Pringle Falls spacing study area. Sloping topography characterizes the ponderosa pine areas both at Pringle Falls and at Twin Lakes in contrast with the low-lying flat area occupied by the Twin Lakes lodgepole pine study.

Size of the difference in soil moisture withdrawal between low and high density plots at Twin Lakes may have been substantially increased by lack of understory development. Barrett (1970) reported that less soil moisture was withdrawn where understory had been removed than where it had been allowed to develop naturally. He further reported that as crowns and roots of both trees and understory developed with the passage of time, an increasing amount of soil moisture was withdrawn. Thus failure of the understory to expand and substantially replace the transpiring needle surface of cut trees probably explains the large difference in soil moisture withdrawal between stands.

Reduction in amounts of snow and rain intercepted by tree crowns and resulting increases in snow stored on the ground are other effects of thinning discussed by Goodell (1952). Under the circumstances of relatively high precipitation where Goodell carried out his studies, the result was greater water yield. However, where soil water storage capacity tends to be greater than precipitation, the result could be more water for tree growth. No effort was made to assess effect of thinning on tree crown interception of rain and snow or on snow storage at Twin Lakes.

Reasoning suggests that differences in understory vegetation density between the Twin Lakes and Pringle Falls sites may account for differences in tree growth. Barrett (1970) reported that where understory vegetation was allowed to develop naturally, the 62 "best" trees per acre out of 1,000 present grew almost as well as the 62

trees left after removing all others. However, when understory vegetation was removed the 62 trees by themselves grew much more rapidly than the 62 "best." At Twin Lakes both diameter growth and volume increment of the 100 largest trees per acre increased steadily as tree density decreased despite the presence of understory. Differences in understory competitiveness may well be the result of differences in quantity of understory.

Differences in environment implied by differences in vegetation may be the principal reason for variations in understory response to thinning between Twin Lakes and Pringle Falls. If this is true, it will be necessary to assess response of understory vegetation to thinning and its effect on tree growth and soil moisture depletion separately for each of the many soil vegetation types.

Increasing susceptibility of lodgepole pine trees to mountain pine beetle attack with increasing tree size is another factor that may have a bearing on the best stand density regime. Amman (1969) and Roe and Amman (1970) point out that large trees with thick phloem are the most likely to be attacked in natural stands. In the stands investigated, age and tree size were correlated (Roe and Amman 1970). Consequently, the question, how susceptible are fast growing young trees of larger size in managed stands, is still unanswered.

The effect of stand density on soil moisture withdrawal and wood production at Twin Lakes and on understory forage production at other study sites (McConnell and Smith 1970) clearly points to an opportunity for manipulation of forest land output to obtain the products most desired. Very young forests present the best manipulation opportunities. A precommercial thinning may often substantially increase usable wood production and at the same time increase both water and forage production. However, as trees grow in size and nearly all wood produced is being added to usable-sized trees, the stand density reduction required to increase forage and water outputs would be at the cost of reduced wood growth.

The main conclusions that have been reached from the Twin Lakes study are:

1. The excellent growth response of young lodgepole pine to thinning means most of the total possible wood producing capacity can be transferred to the relatively small number of trees that can reach usable size.

2. Understory vegetation did not develop as vigorously at Twin Lakes as Barrett reported at Pringle Falls. Reasoning from Barrett's Pringle Falls results suggests that differences in vegetation development will affect tree growth. Consequently, different understory responses to thinning from one soil

vegetation type to another may trigger different tree growth and soil moisture withdrawal responses.

3. The low stand density that fostered rapid individual tree growth and reduced evapotranspiration drain on soil moisture favored merchantable timber production and may have increased water yield as well at Twin Lakes. However, as trees begin to reach usable size and there is a desire to keep them in full possession of the site, the goal of near maximum wood production is not compatible with reducing transpiration drain on soil water by reducing tree density.

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A lodgepole pine levels-of-growing-stock study showed that individual trees developed longer crowns, grew more rapidly and added more wood to potentially merchantable trees at lower stand densities, but total wood production was less. Evapotranspiration drain on soil moisture was also less at the lower stand densities.

Keywords: Soil moisture, stand density, lodgepole pine, forest measurement.

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